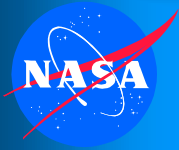




# A General Approach to MEMS Reliability Assurance

**Joanne Wellman--JPL**

This work was carried out at the Jet Propulsion Laboratory,  
California Institute of Technology, under contract with the  
National Aeronautics and Space Administration, Code AE,  
under the NASA Electronics Parts and Packaging Program (NEPP)



# MEMS RELIABILITY ASSURANCE



## Other Contributors:

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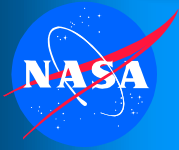
*Ron Ruiz*

*Ken Evans*

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*Helen Avila*

*Prudencio Alonso*

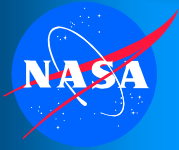


# MEMS RELIABILITY ASSURANCE



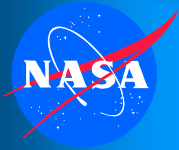
## OUTLINE

- MEMS Reliability Concerns
- Our approach to MEMS Reliability
- MEMS Reliability Alliance
  - In theory
  - In practice



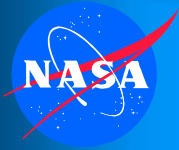
## RELIABILITY ISSUES: MATERIAL PROPERTIES

- *Fracture/failure mechanisms*
- *Elastic modulus*
- *Poisson's ratio*
- *Fracture toughness*
- *Electrical properties (migration, etc.)*
- *Interfacial strength*
- *Coefficient of thermal expansion (CTE)*



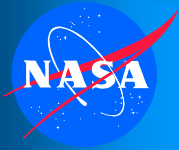
## RELIABILITY ISSUES: PROCESSING

- *Residual stresses*
- *Grain size*
- *Stiction phenomena*
- *Doping*
- *Etching parameters*
- *Surface roughness*
- *Deposition methods, parameters*
- *Post-process release etching*
- *Post-process drying method (stiction)*



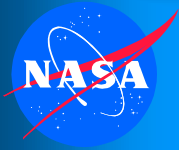
## RELIABILITY ISSUES: DEVICE-LEVEL METROLOGY

- *Grain size*
- *Surface roughness*
- *High resolution cross-sectioning*
- *Microscale crack propagation visualization*
- *Real time performance (movement) visualization*
- *Device design effects (corners, etch holes, etc.)*



## FABRICATION, MANUFACTURING VARIATIONS

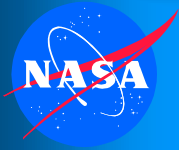
- *Doping*
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## RELIABILITY ISSUES: ENVIRONMENTAL EFFECTS

- *Storage, humidity effects*
- *Radiation tolerance*
- *Chemical exposure effects*
- *Biocompatibility*
- *Effects of extreme heat or cold*
- *Effect of shock*



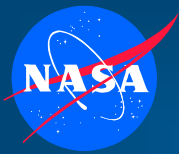


# MEMS RELIABILITY ASSURANCE



## RELIABILITY ISSUES: SYSTEM-LEVEL

- *Packaging effects*
- *Support electronics, noise*
- *Fatigue and long term operation effects*

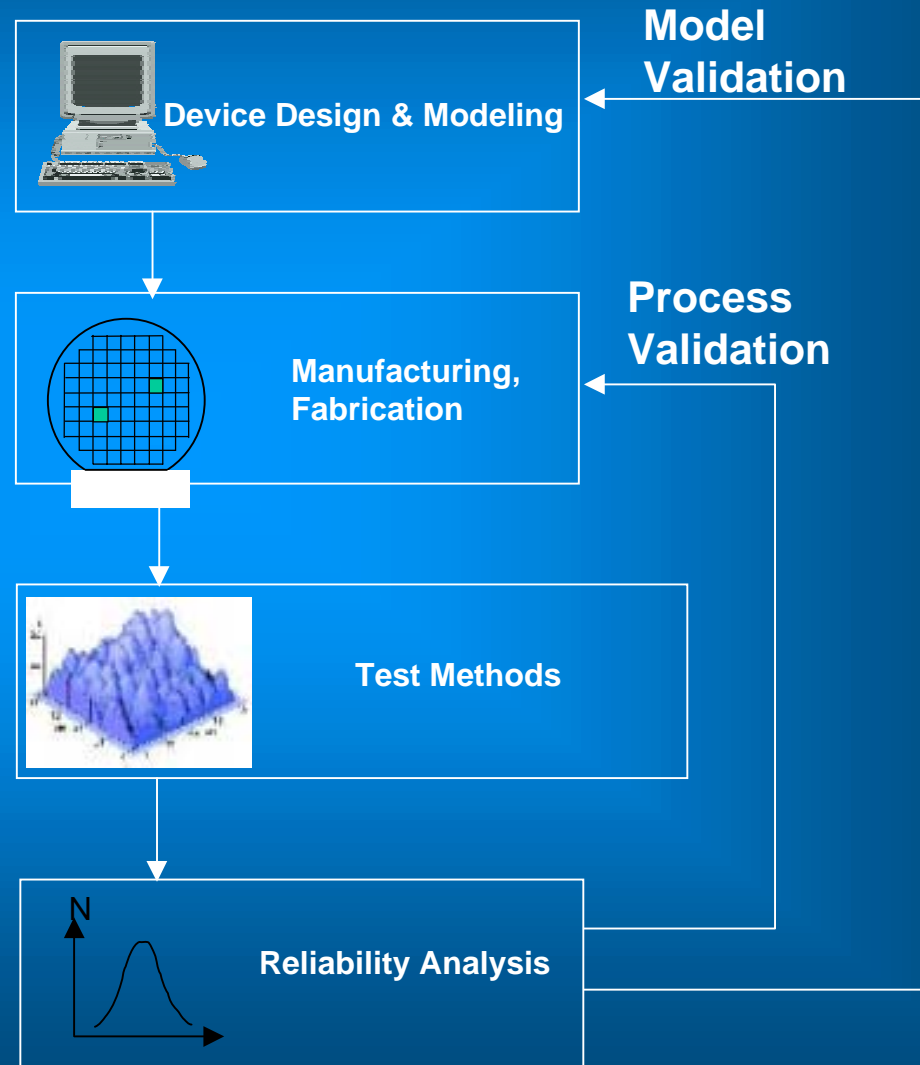


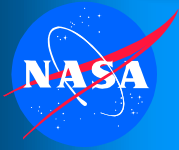
# MEMS RELIABILITY ASSURANCE



## Our Approach to MEMS Reliability

*Feed test results and characterization of MEMS devices back into the design, modeling, and fabrication phases of MEMS development and production.*





# MEMS RELIABILITY ASSURANCE



## MEMS Reliability Alliance

**MEMSCAP:**

*Design Tools  
Model Validation*

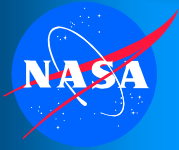
**CRONOS/**

**JDS Uniphase:**

*MEMS Foundry/Parts  
Process Characterization*

**JPL:**

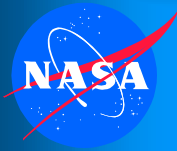
*Design MEMS Test Structures  
Characterization/Testing  
Space Flight Qualification*



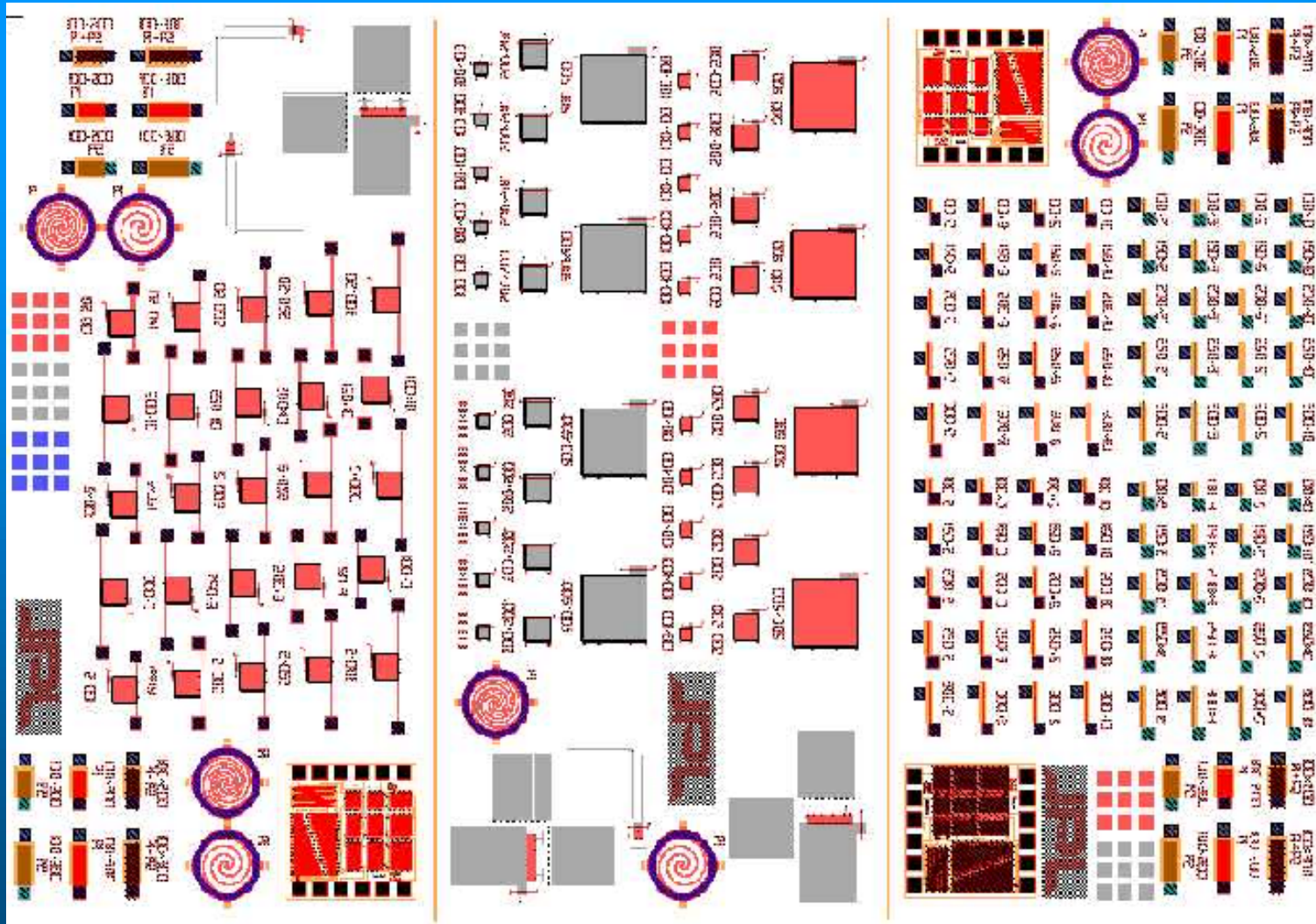
## MUMPs™ layer stack.

<i>Metal (0.5 <math>\mu</math>m)</i>
<i>Poly2 (1.5 <math>\mu</math>m)</i>
<i>Oxide2 (0.75 <math>\mu</math>m)</i>
<i>Poly1 (2 <math>\mu</math>m)</i>
<i>Oxide1 (2 <math>\mu</math>m)</i>
<i>Poly0 (0.5 <math>\mu</math>m)</i>
<i>Nitride (0.6 <math>\mu</math>m)</i>
<i>Silicon Substrate</i>

*Poly1 and poly2 are structural polysilicon layers, while the oxides are sacrificial layers in that they do not appear in the final structure. Poly0 is used as a ground plane and the nitride is used for electric isolation. Metal layer on top (gold) is for optional contact metalization.*

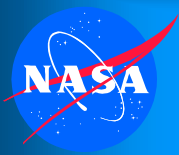


# MEMS RELIABILITY ASSURANCE



*Footprint of MUMPS run 36 test structures*

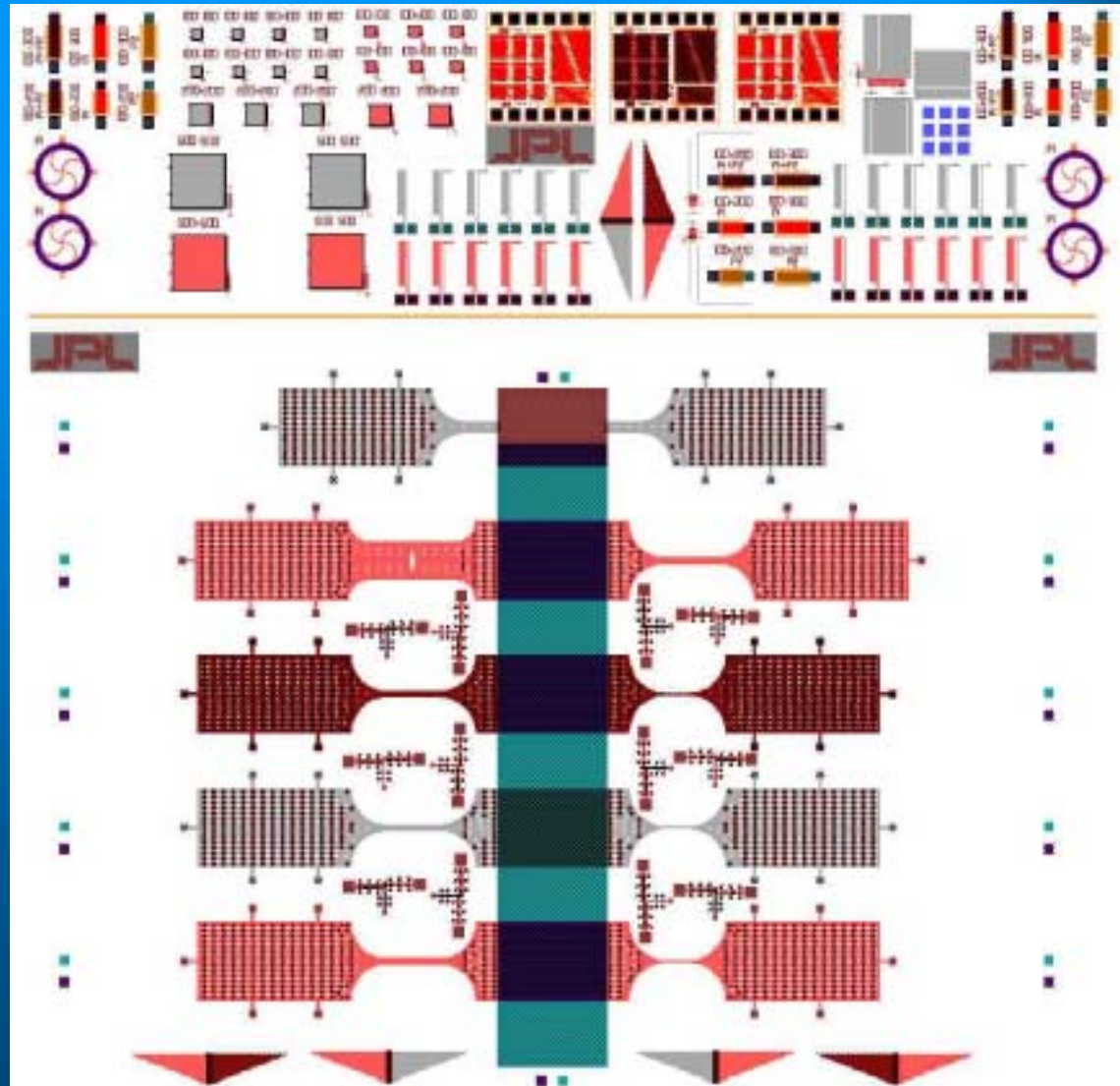


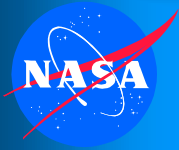


# MEMS RELIABILITY ASSURANCE



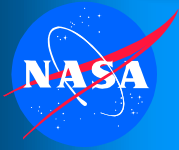
*Footprint of  
MUMPS run 37  
test structures*





## Test Structure Types:

- *Poly1 and poly2 clamped-clamped and clamped-free cantilever beams for residual stress and elastic modulus assessment*
- *Wide polysilicon cantilevers*
- *Stiction beam test array*
- *Hinged flap array for post-process residue study*
- *Vibration test structure*
- *Test array to measure torsional shear and change in resistance due to torsion in polysilicon*
- *Fracture toughness test structures*
- *Polysilicon fracture test structure array*
- *In-plane residual stress visual readout verniers*



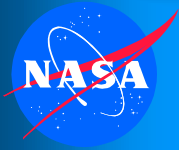
## Material Properties:

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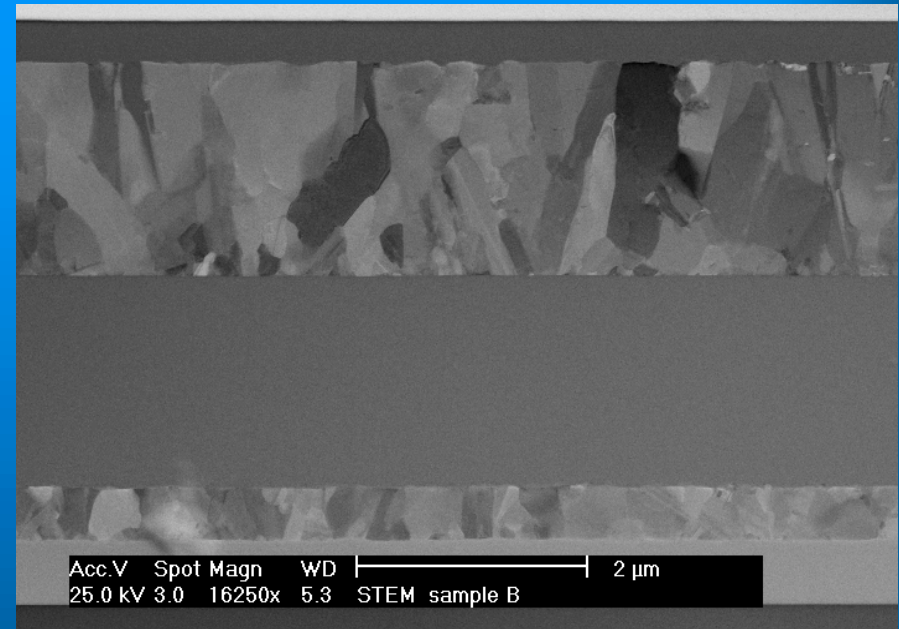
**3000X SEM image of fractured unreleased cantilever beam array damaged during dicing.**



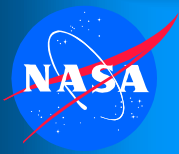


## Process Feedback

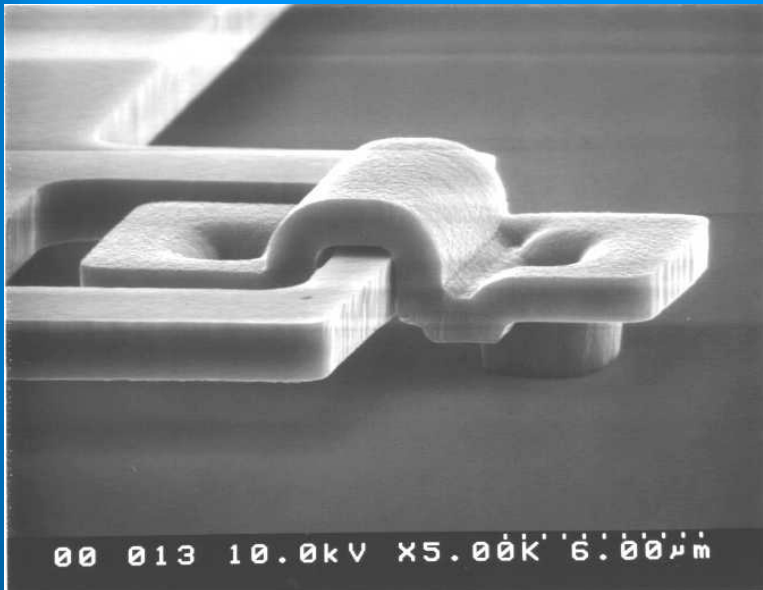
- *Residual stresses*
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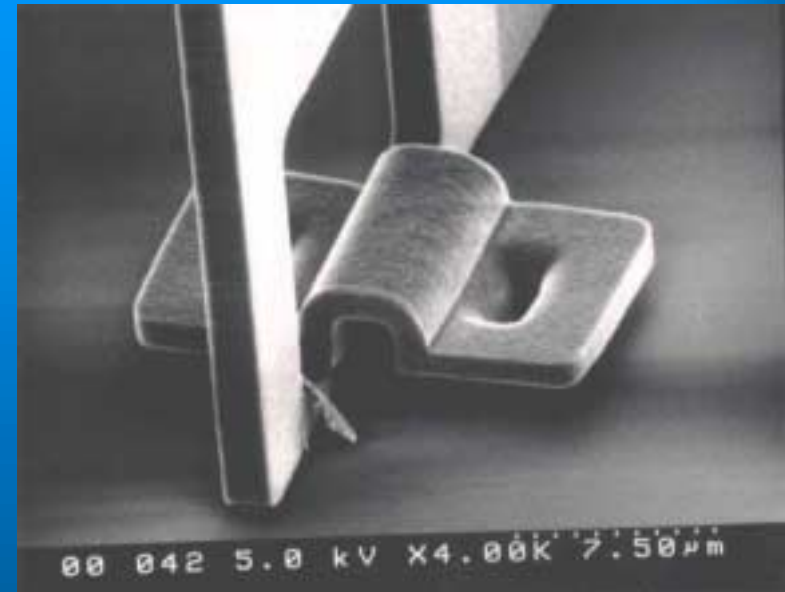
*High-resolution STEM image of oxide and polysilicon layers deposited in MUMPS process. Notice the clear definition of grain boundaries and interfaces.*



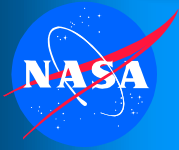
## Process Variations



*SEM side view of a poly2 hinge after poly1 plate has been rotated 180°, showing the ridge created by the dimple clearly*

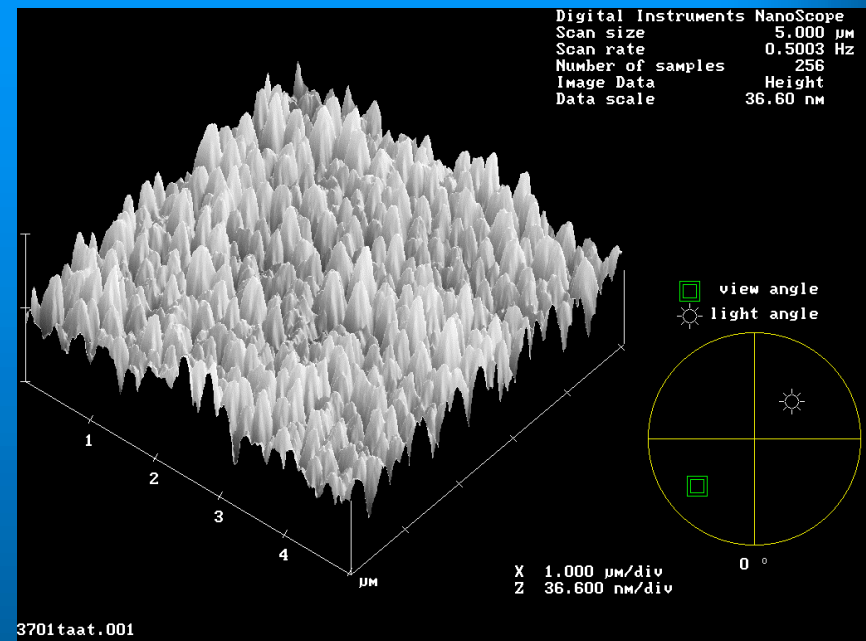


*SEM photo of a hinge without the dimple patterned through it. While rotating the poly1 plate, the hinge pin got pegged under the poly2 staple. Any further rotation will break the pin. Also, rotation of the poly1 plate is now irreversible.*

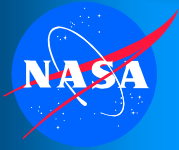


## Environmental Effects:

- *Storage, humidity effects*
- *Radiation tolerance*
- *Chemical exposure effects*
- *Biocompatibility*
- *Effects of extreme heat or cold*
- *Effect of shock*



*AFM images of the top of a poly2 layer after sacrificial layer removal for A MUMPs 37 chip. Scan size is  $5\mu\text{m} \times 5\mu\text{m}$  and height data scale on the order of 40 nm.*



# MEMS RELIABILITY ASSURANCE



## FUTURE PLANS:

- *Complete testing and analysis on existing test structures*
- *Expand library of test structures*
- *Expand MEMS Reliability Alliance to include new processes*
- *Include functional devices (not test structures) into reliability framework*